EICUG Working Group on Polarimetry

Elke Aschenauer

BNL

Dave Gaskell

Jefferson lab

Outline

- Charge
- Polarimetry Requirements and Goals
- Electron Polarimetry
- Hadron Polarimetry
- Working Group Plans

Charge

Charge: The EICUG Polarimetry working group's mission is to plan and/or develop the optimal methods and techniques for measuring the absolute polarization (and polarization direction) of the electron and ion beams with high precision. It is strongly suggested that the new EICUG Polarimetry working group interface directly with existing efforts at BNL and JLab, and with the other EICUG working groups. The working group will be open to all members of the EICUG. It will communicate via a new mailing list and organize regular online and in-person meetings that enable broad and active participation from within the EICUG as a whole.

There have been ongoing efforts at BNL and Jefferson Lab, but involving a relatively small group
→ One of the main goals of EICUG Working Group on Polarimetry is to involve a larger group to help with the R&D required for achieving EIC polarimetry goals

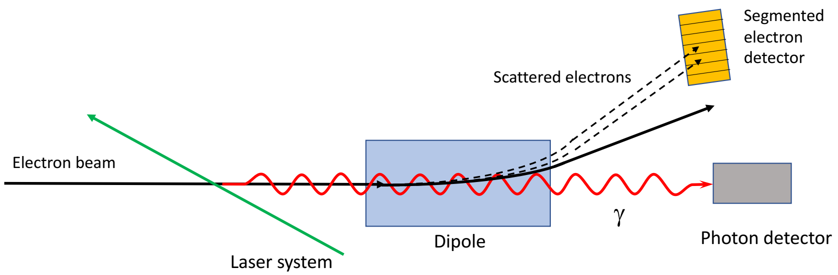
Polarimetry Requirements

- Nominal polarimetry precision target is dP/P ~ 1-2% for both electron and hadron beams
  - Precision driven both by physics asymmetries as well as luminosity measurements

$$\sigma_{BH} = \sigma_0(1 + P_e P_p A_{BH})$$

  - State of the art for electron polarimetry ~ 0.5%, so 1% at EIC should be tractable - although novel EIC properties present challenges
  - State of the art for proton polarimetry is approaching <2%, but significant challenges remain

Electron (Compton) Polarimetry



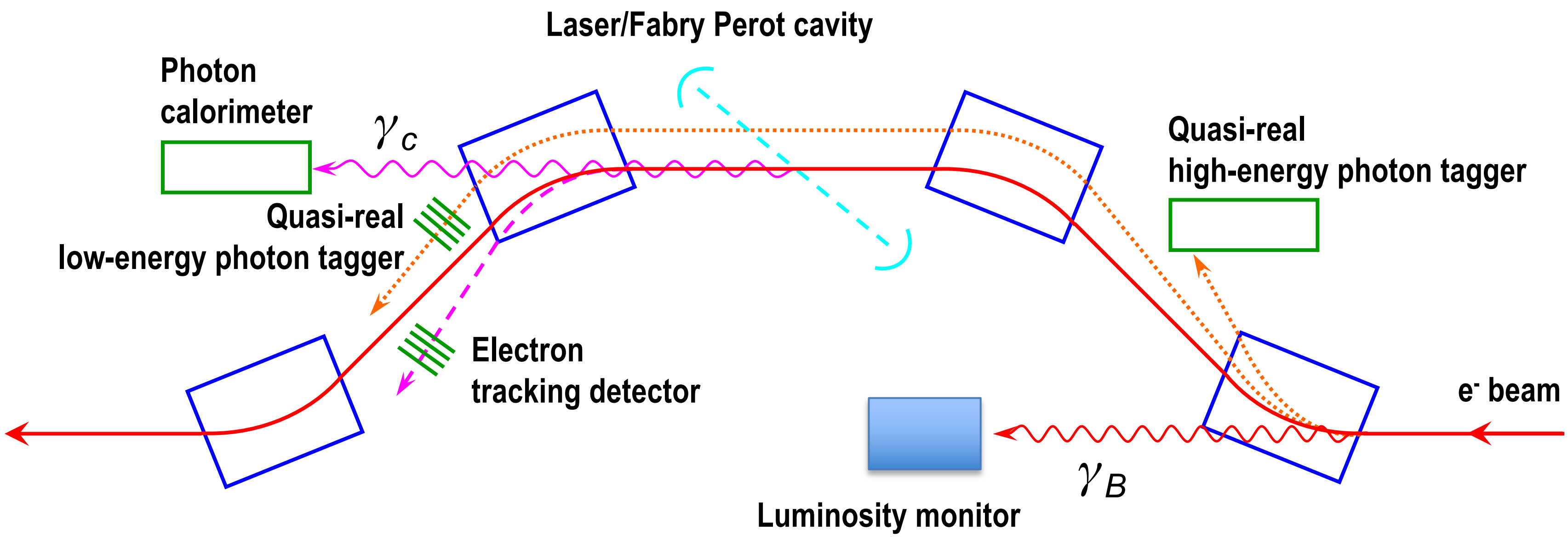
Polarimeter	Energy	Sys. Uncertainty
CERN LEP*	46 GeV	5%
HERA LPOL	27 GeV	1.6%
HERA TPOL*	27 GeV	2.9%
SLD at SLAC	45.6 GeV	0.5%
JLAB Hall A	1-6 GeV	1-3%
JLab Hall C	1.1 GeV	0.6%

Compton polarimetry has been used extensively in both fixed-target and collider environments – standard technique in storage rings since it is non-destructive

→ Highest precision has been achieved using electron detection, for longitudinally polarized electrons

Compton Polarimetry at JLEIC

- At JLEIC, Compton can share chicane with low Q^2 tagger
- Laser-electron collisions in middle of chicane assures no spin rotation relative to IP
- No interference with electron detectors needed for low Q^2 tagger

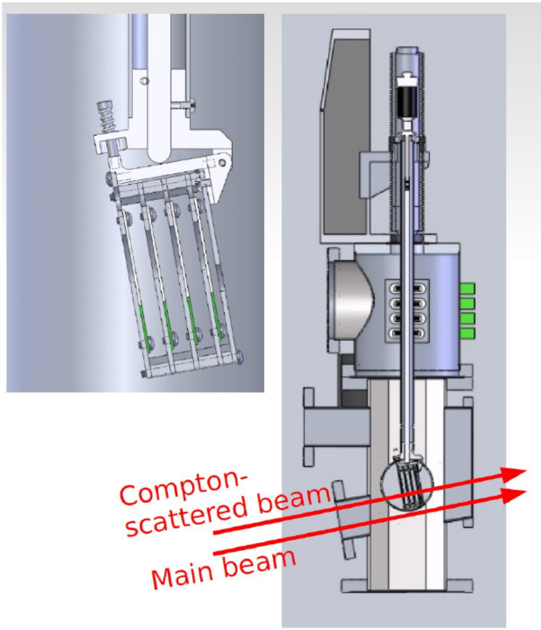


Compton Electron Detector R&D Project

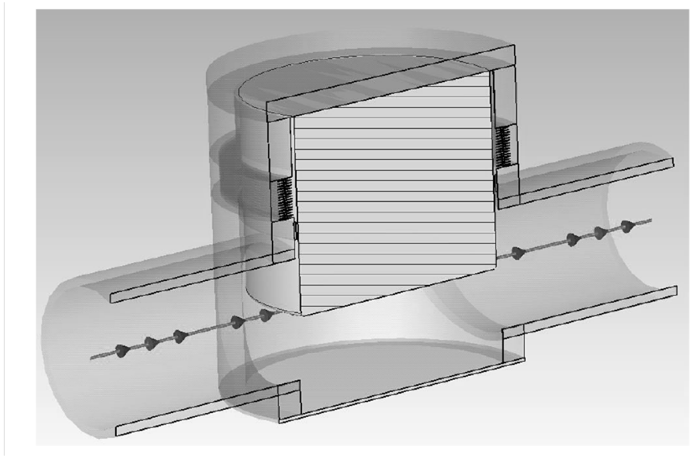
EIC Detector R&D Project for development of electron detection scheme for Compton polarimetry (A. Camsonne, J. Hoskins, et. al.)

→ Default design based on diamond strip detectors similar to those used in Hall C at JLab, but placed in Roman Pot rather than beam vacuum

→ Simulations targeted at understanding backgrounds and studying achievable precision

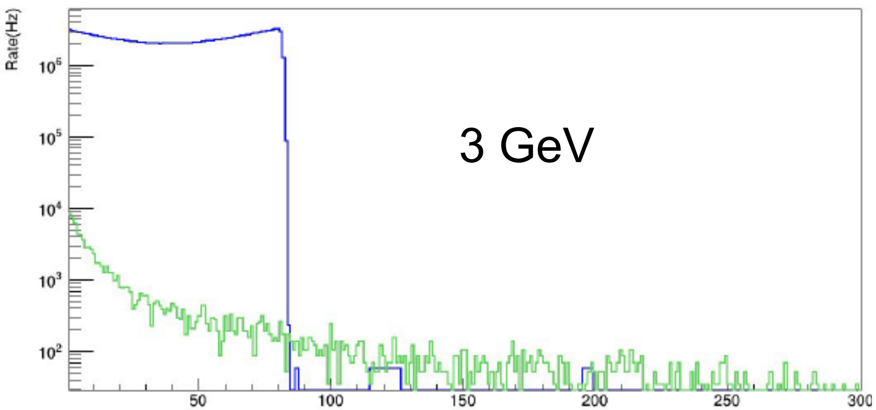


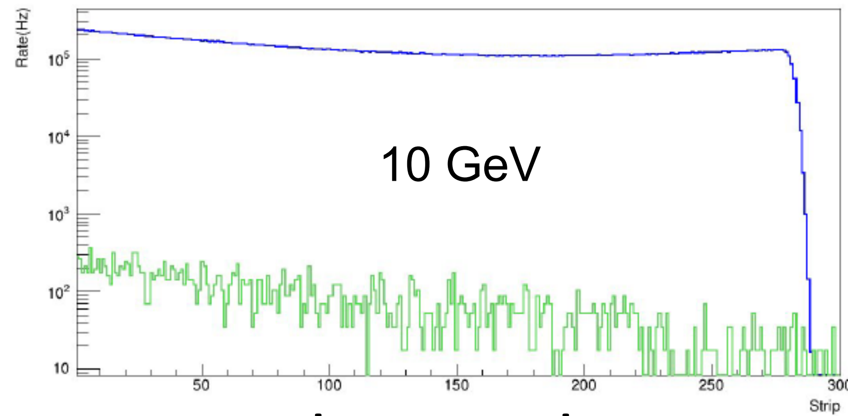
TOTEM Roman Pot

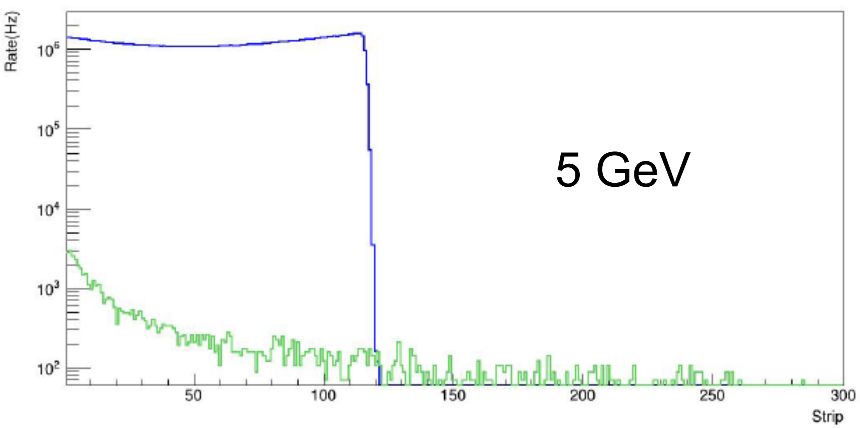


Compton Signal and Backgrounds at JLEIC

– Signal to background different energies







- 1 A electron beam
- 10^{-9} torr
- 10 W CW laser
- Bremsstrahlung is ok at all energies

Effect of Roman Pot Window

Energy	Thickness	Polarization	Error
3	50	-97.02	+/-0.67
3	500	-96.60	+/-0.90
3	1000	-95.82	+/-0.81
5	50	-97.69	+/- 0.58
5	500	-96.59	+/- 0.79
5	1000	-96.68	+/- 0.50
10	50	-97.19	+/- 0.17
10	500	-97.19	+/- 0.24
10	1000	-97.02	+/- 0.20

- polarization correction at 3 and 5 GeV due to thickness
- consistent with input polarization of 97% within 1% error bar

Compton Polarimetry Challenges

- Compton polarimetry must confront several challenges common to both JLEIC and eRHIC designs
  - Large electron beam currents lead to significant synchrotron radiation
  - Desirable to measure all components (longitudinal and transverse) of beam polarization at once
- JLEIC-specific challenges
  - High beam frequency makes bunch-by-bunch polarization measurement (if needed) challenging
  - Electron detection scheme somewhat sensitive to beam halo – must be understood

Compton Polarimetry at eRHIC

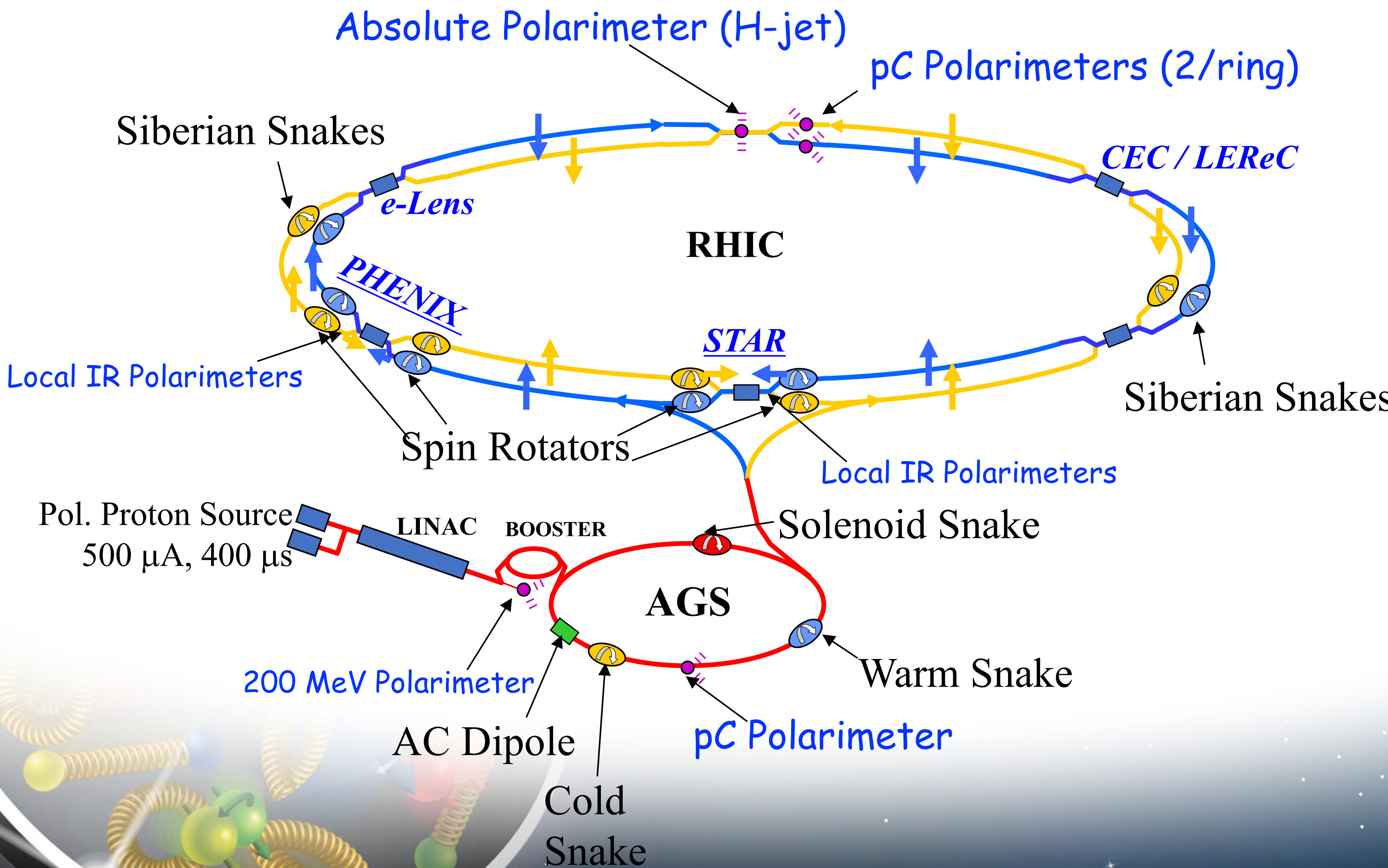
- Storage Ring: Both lepton and hadron polarimetry at IP-12
  - lepton polarization direction transverse
    - need to measure precisely spatial asymmetry in Compton scattering (only done once at HERA (TPol))
    - want to measure also longitudinal component
  - no special chicane, use transition into arc to separate Compton photon and lepton from core of the beam
    - location with minimized synchrotron radiation

- Rapid cycling synchrotron:
  - Polarization measurement for machine tuning
  - 100 ms ramp from 400 MeV to 18 GeV; 1Hz ramp repetition rate; 10 nC in bunch

  → this polarization measurement will not be an easy task

Lets learn from RHIC

RHIC the world's only polarized hadron collider



Concept for Hadron Polarimetry

Polarized hydrogen Jet Polarimeter (HJet)

- Source of absolute polarization (normalization of other polarimeters)
- Slow (low rates ⇒ needs looong time to get precise measurements)

Proton-Carbon Polarimeter (pC)

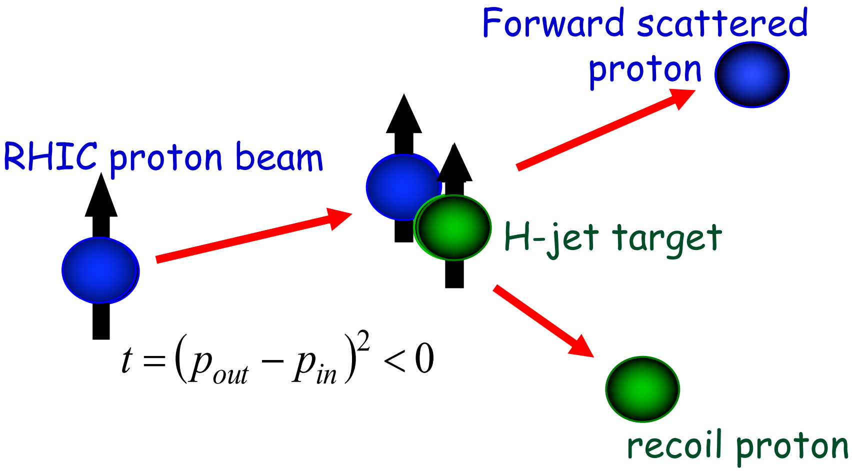
- Very fast and high precision ⇒ main polarization monitoring tool
- Measures polarization profile and lifetime
- Needs to be normalized to HJet

IR Local Polarimeters

- Defines spin direction and degree of rotation in experimental area

All of these systems are critical for polarization measurements and monitoring at RHIC
→ Will be critical for EIC

Polarized H-Jet Polarimeter



$$t = (p_{out} - p_{in})^2 < 0$$

Left-right asymmetry in elastic scattering due to spin-orbit interaction:
interaction between (electric or strong) field of one proton and magnetic moment associated with the spin of the other proton

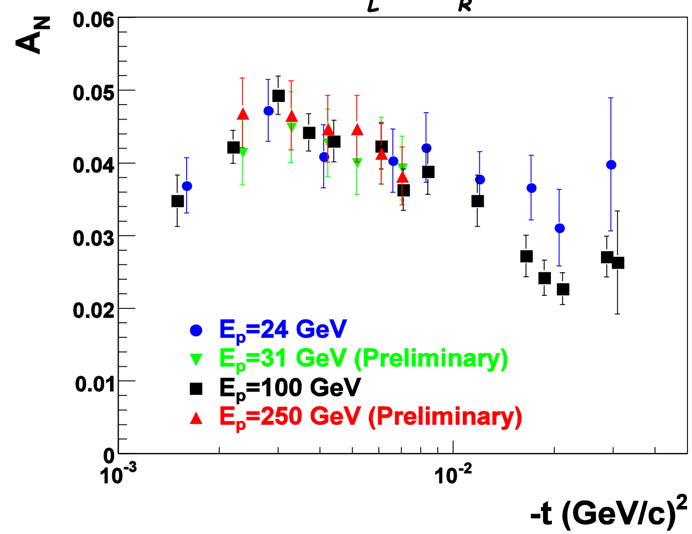
Beam and target are both protons:

P_{target} from Breit Rabi Polarimeter

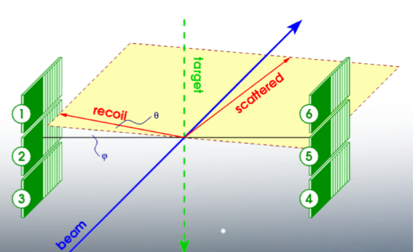
$$A_N(t) = \frac{\varepsilon_{target}}{P_{target}} = \frac{\varepsilon_{beam}}{P_{beam}}$$

$$P_{beam} = P_{target} \frac{\varepsilon_{beam}}{\varepsilon_{target}}$$

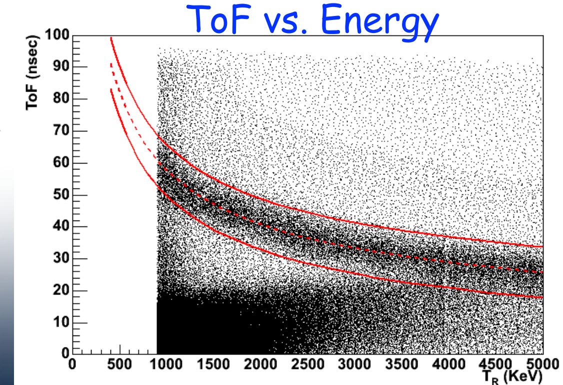
$$A_N = \frac{N_L - N_R}{N_L + N_R} = \frac{\varepsilon_N}{P}$$



Array of Si detectors measures T_R & ToF of recoil proton.
Channel # corresponds to recoil angle θ_R.
Correlations (T_R & ToF) and (T_R & θ_R) → the elastic process

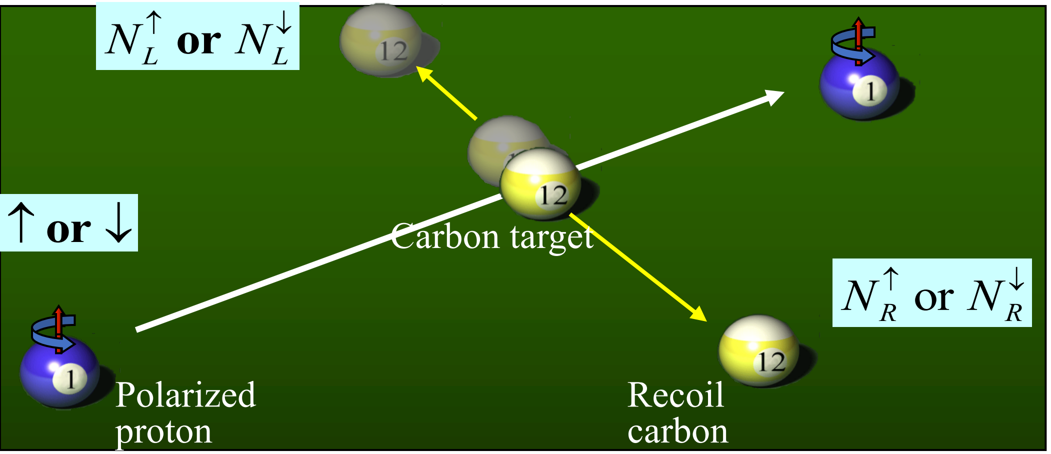


ToF vs. Energy



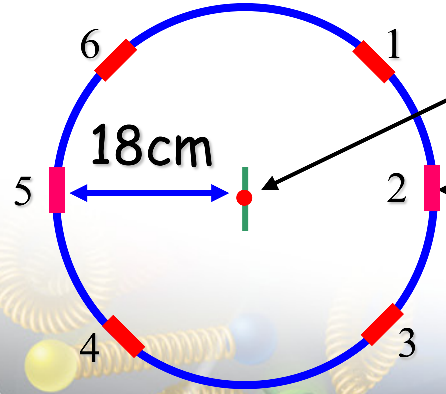
P-Carbon Polarimeter:

Left-right asymmetry in elastic scattering due to spin-orbit interaction: interaction between (electric or strong) field of Carbon and magnetic moment associated with the spin of the proton



$$P_{beam} = -\frac{\varepsilon_N}{A_N^{pC}}$$

$$\varepsilon_N = \frac{N_L - N_R}{N_L + N_R}$$



Target Scan mode (20-30 sec per measurement)

Stat. precision 2-3%

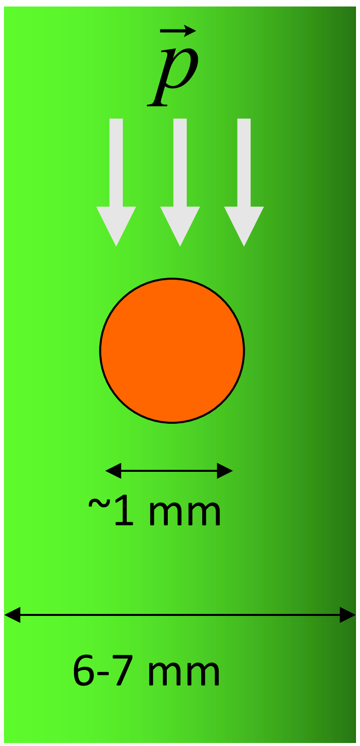
Polarization profile, both vertical and horizontal

Normalized to H-Jet measurements over many fills (with precision <3%)

Polarization Profile

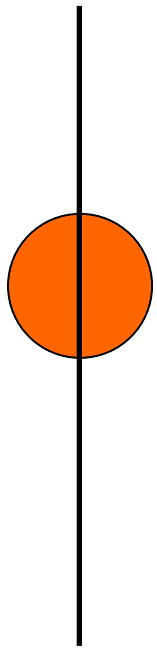
If polarization changes across the beam, the average polarization seen by Polarimeters and Experiments (in beam collision) is different

H-Jet



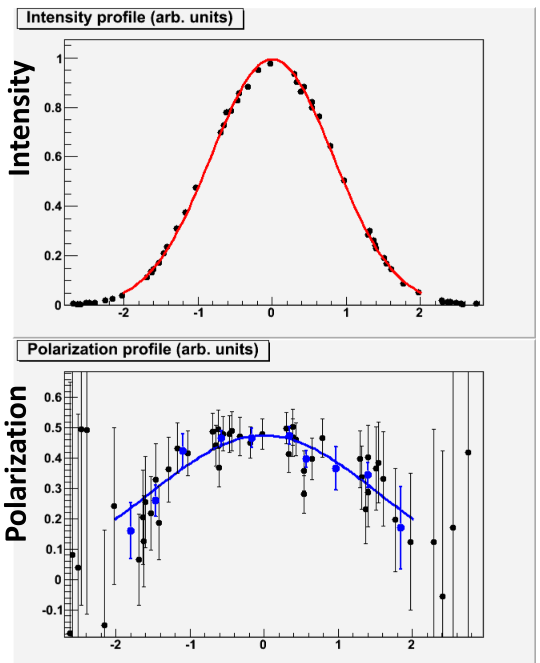
$$\langle P_1 \rangle = P_1(x,y) \otimes I_1(x,y)$$

pC



$x=x_0$

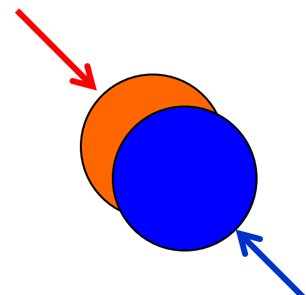
Scan C target across the beam in both X and Y directions



Target Position

$$\langle P_1 \rangle = P_1(x_0,y) \otimes I_1(x_0,y) \quad R = \frac{\sigma_I^2}{\sigma_P^2} \quad \frac{\langle P \rangle_{Exp}}{\langle P \rangle_{HJet}} \approx 1 + \frac{1}{4}(R_X + R_Y)$$

Collider Experiments



$$\langle P_1 \rangle = P_1(x,y) \otimes I_1(x,y) \otimes I_2(x,y)$$

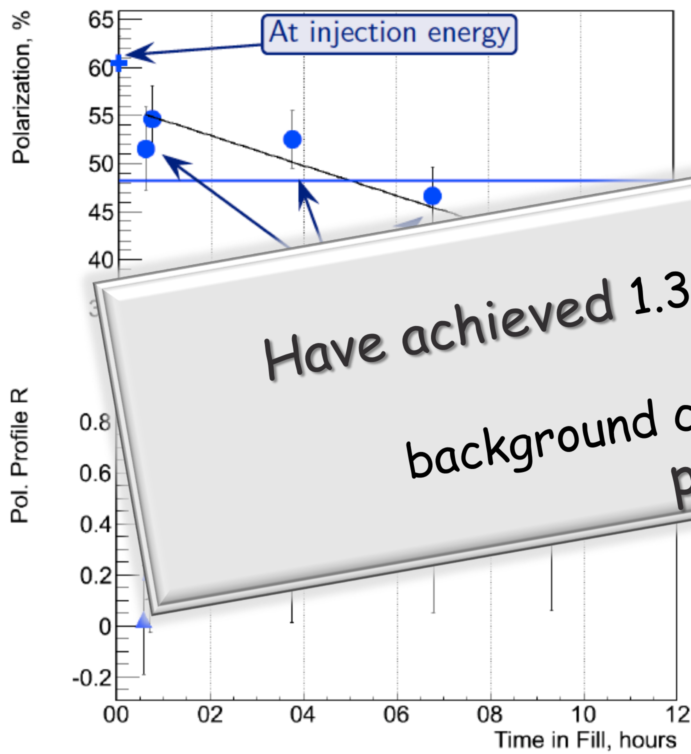
$P_{1,2}(x,y)$ – polarization profile, $I_{1,2}(x,y)$ – intensity profile, for beam #1 and #2

RHIC Hadron Polarisation

Account for
beam polarization decay through fill → $P(t)=P_0 \exp(-t/\tau_p)$
growth of beam polarization profile R through fill

pCarbon polarimeter

Collider Experi...

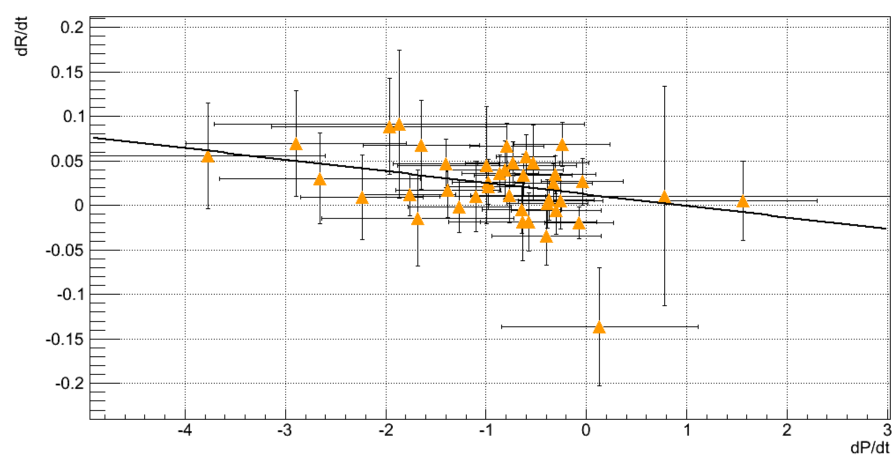


Result:

Have achieved 1.3% for Blue and 2.1% for Yellow beam for 2017
Biggest contributions
background correction for Hjet (1.2% blue / 2% yellow)
pC/H-Jet normalization 0.5%

... all 2012 fills
at 250 GeV

$$R = \frac{\sigma_I^2}{\sigma_P^2}$$



Polarization lifetime has consequences for physics analysis
→ different physics triggers mix over fill
→ different <P>

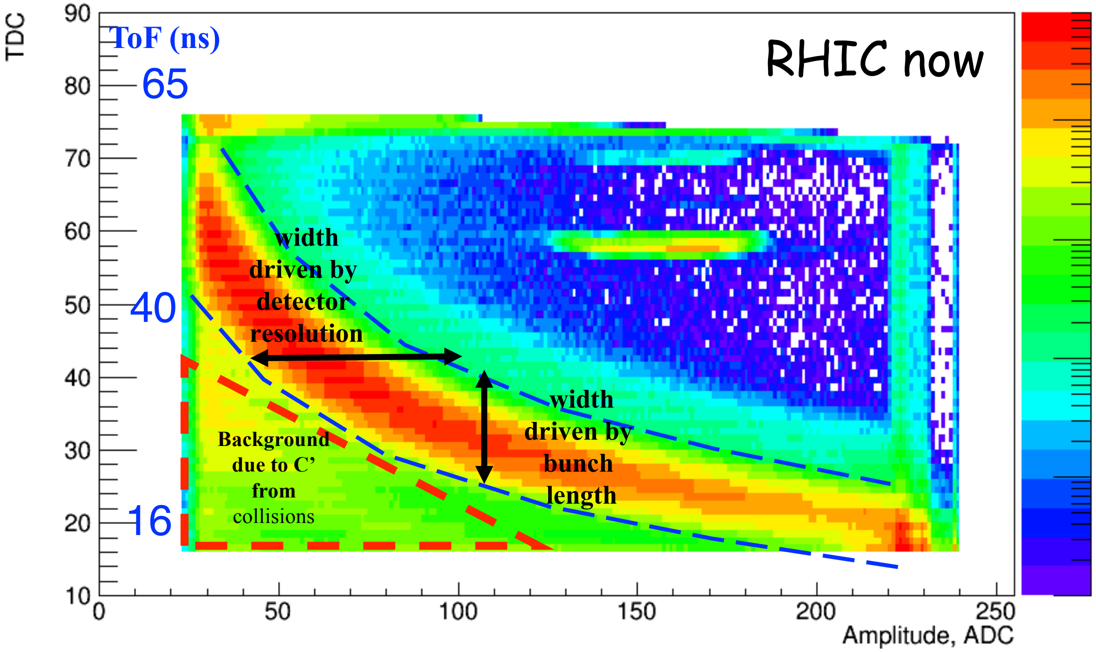
Straight forward Improvements for Hadron Polarimetry

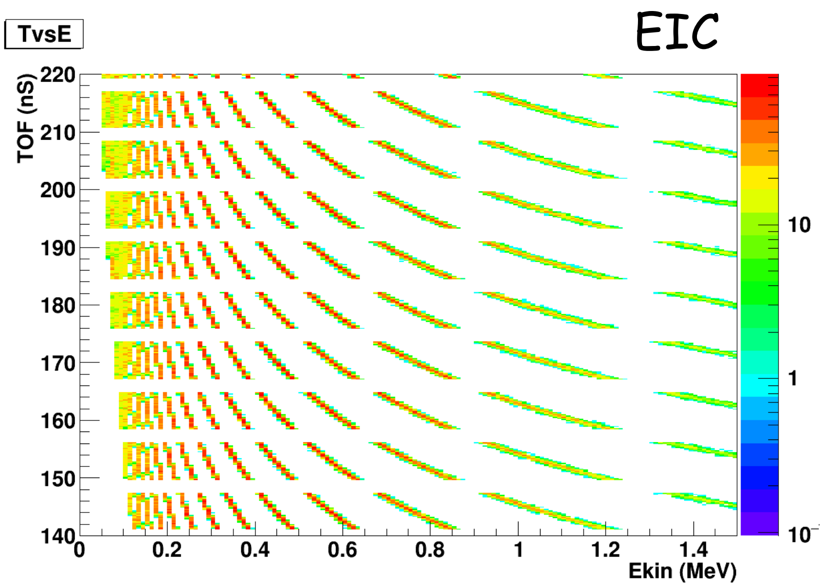
- H-Jet:
  - continuously monitor molecular fraction in the H-Jet
    - ✓ currently dominant systematics
      - → Recent research indicates a significant reduction
- pC-polarimeters
  - find longer lifetime and more homogenious target material for the pC polarimeters
    - ✓ Need to account for higher peak currents in EIC → RF pickup
  - can we calibrate energy scale of pC closer to E_{kin}(C) in CNI
  - alternative detector technology for Si-detectors to detect C?
  - emittance of eRHIC hadron beam → x-y polarization profile
    - ✓ RHIC: 2.5/2.5 e^{-6} m
    - ✓ eRHIC: 9.0/1.3 nm with cooling 13.9/8.5 no cooling
- polarised Deuterium and He-3 polarimetry will be challenging
  - what does the D and He-3 break up do to the polarization measurement
  - would H-jet + D / H-jet + He-3 beam work as absolute polarimeter?
- local polarimetry @ eRHIC
  - integrate a pC-polarimeter between the spin-rotators
    - ✓ Magnitude of asymmetry directly proportional to longitudinal polarization

Hadron Polarimeter Challenges

Collision Frequency Challenge:

RHIC: 100 ns → eRHIC$_{Max}$: 8.7 ns JLEIC: 2ns





- increased bunch number signal "bananas" overlap at low E_{kin}
  → lose data with highest statistics and high analyzing power
- EIC: No background included and no smearing in horizontal due detector energy resolution and energy loss in target
  - → smearing need to increase lower cut on E_{kin} → lose data with high statistics & high analyzing power
  - → collision related C' background
    smears from (N+1)s bunch to Ns bunch and lower → impact on measuring bunch polarization
  - → RHIC data background has opposite sign to signal region

Need to work hard to make current scheme work

Polarimetry Working Group Plans

Communication will proceed via EICUG Working Group mailing list:

https://groups.google.com/a/eicug.org/forum/#!forum/eicug-polarimetry

→ Can join directly using Google email address, or send us your (other) email address and we will add you

Web site will also be created, but format still under discussion

Long term aim is to have focused working group meetings on the order of every 6 months

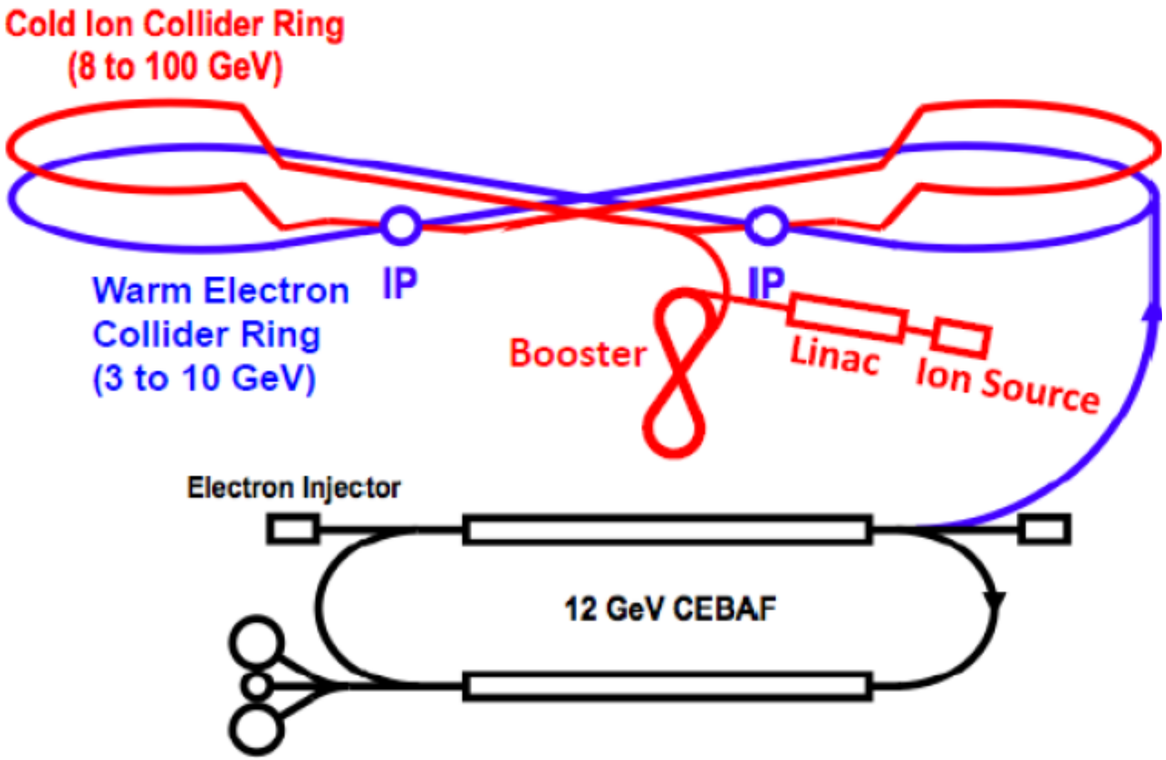
→ Often meetings will coincide with EICUG meetings

→ Other meetings may try to target polarimetry experts not already associated with EIC by scheduling satellite meeting associated with other spin-related conferences (e.g. PSTP)

Online meetings and discussions will also be an important component of this Working Group


BACK UP

JLEIC Electron Beam Structure and Polarization

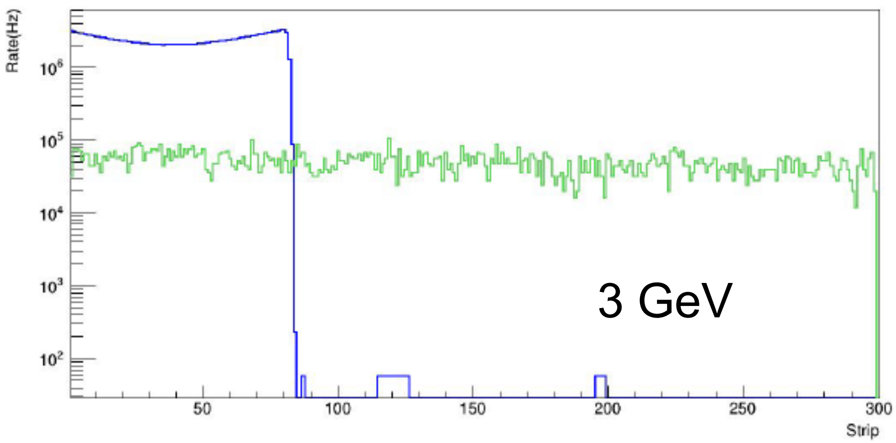


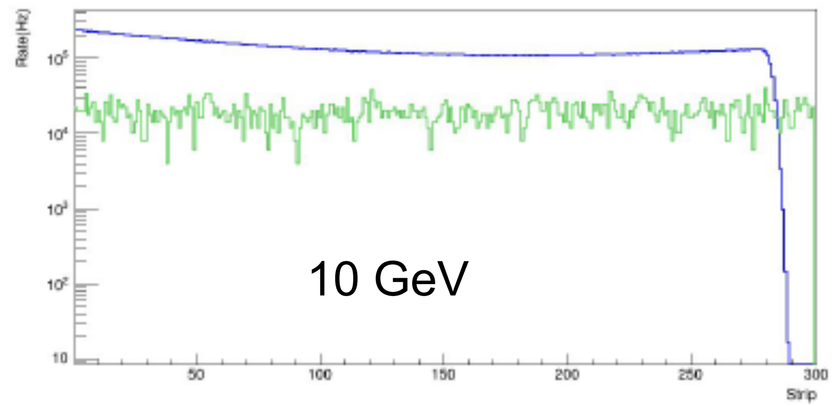
- Storage ring: 476.3 MHz = 2.1 ns bunch structure
- 3 A at 5 GeV and 720 mA at 10 GeV
- 2 macrobunches with one polarization; each macrobunch = 3.2 μs

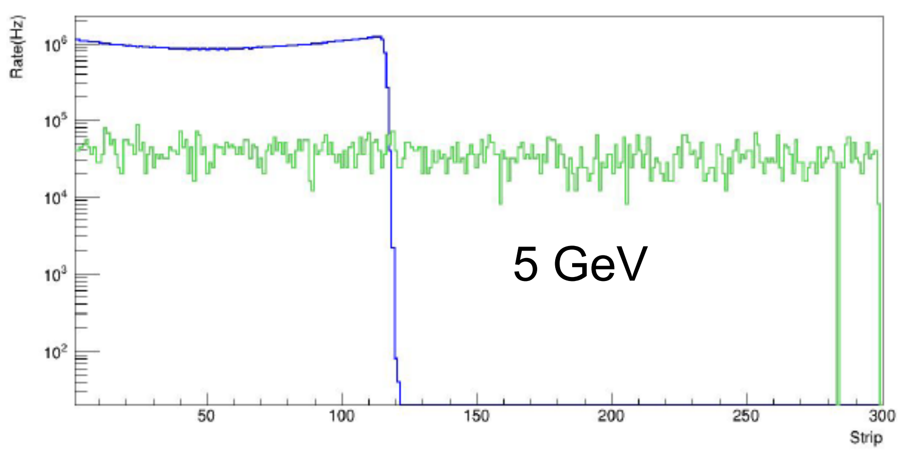
Precision Compton Polarimetry

- Precision goal for electron beam polarization is dP/P= 1%
- Sub-1% polarimetry has been achieved at:
  - SLD → 0.52% at 45.6 GeV (electron detection)
  - JLab Hall A → 1-3 GeV (electron and photon detection)
  - JLab Hall C → 1 GeV (electron detection)
- Sub-1% precision has only been achieved via photon detection using threshold-less, “integrating” technique
  - Large synchrotron backgrounds at JLEIC may make this impossible
- For now, the JLEIC Compton design emphasizes detection of the Compton scattered electron

Halo contribution for Electron Detector







- 1 cm aperture
- S/B still around 10
- 10 W CW laser no need for aperture unless need more power with cavity

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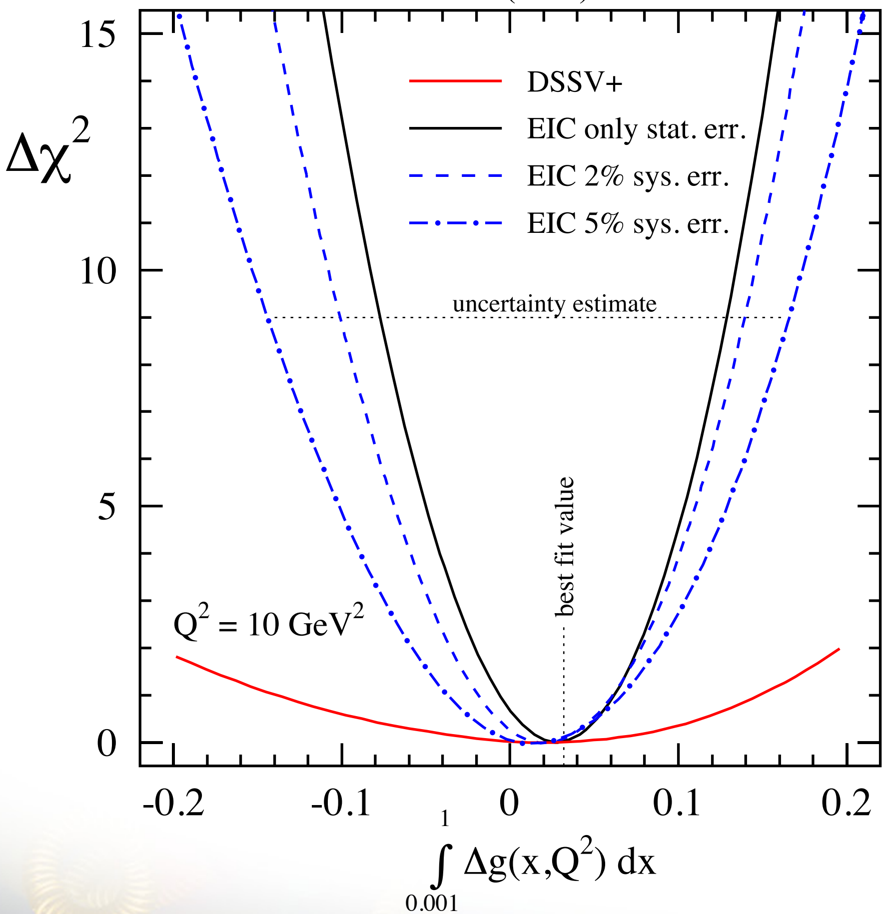
Impact on ∫Δg from systematic uncertainties

arXiv: 1206.6014 PRD 86 (2012) 054020



Dominant systematics:

Luminosity Measurement → Relative Luminosity

$$A_{LL} = \frac{1}{P_e P_p}\left(\frac{N^{++/--} - RN^{+-/-+}}{N^{++/--} + RN^{+-/-+}}\right); \text{ with } R = \frac{L^{++/--}}{L^{+-/-+}}$$

relative luminosity

→needs to be controlled better then A_{LL}
→~10^{-4} at low x

Absolut polarization measurements:
electron P_e and hadron P_p

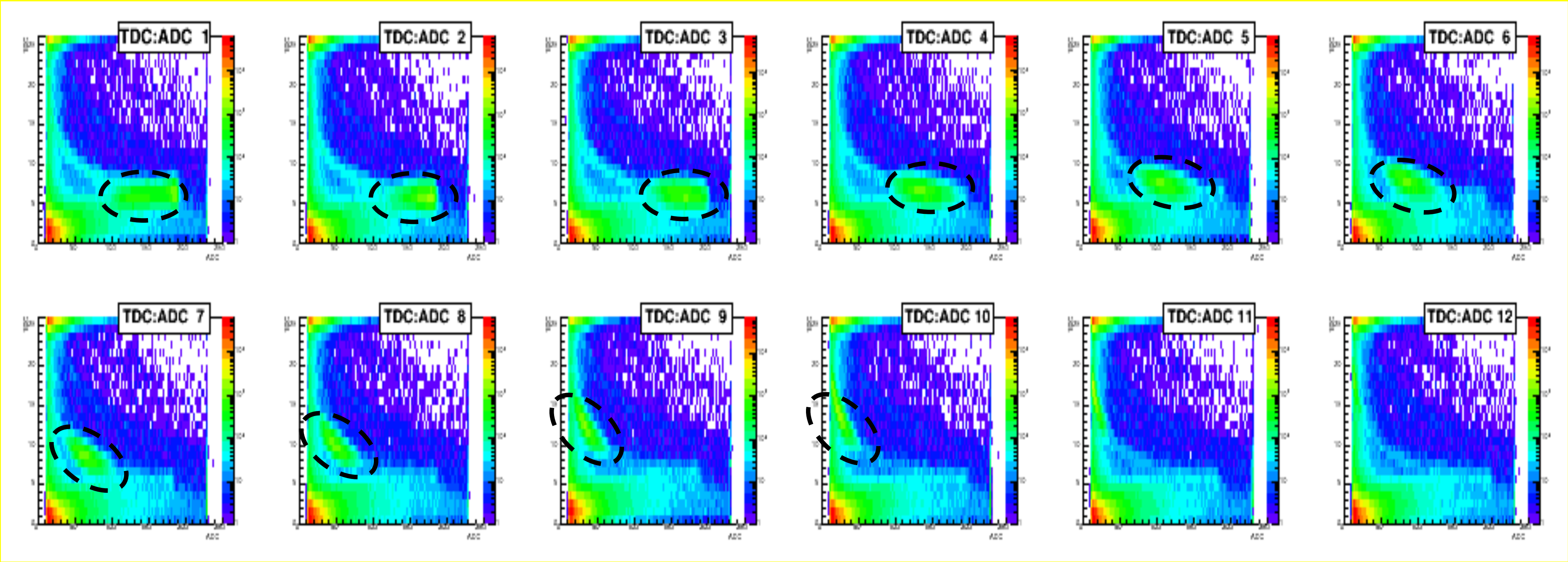
Need systematics ≤ 2%

Possible Mitigations

- Need simulations to understand exact origin of collisions related C' background
  - → can we reduce / eliminate this background?
    - Move detectors closer → reduced ToF → mitigates merging of signal "bananas" at low E_{kin}
      - loss of ToF resolution / separation
  - → can we change detector technology to have better energy and timing resolution
    - higher timing resolution Si: 16 ps
  - → can we experimentally suppress the background → PID

- Can we utilize different techniques to replace pC polarimeters
  - → Use physics asymmetries:
    - A_N for $\pi^{+/-}$ π^0
    - A_N for neutrons in $p^{\uparrow}A$-scattering
    - Possible Advantages
      - Sometimes larger analyzing power
    - Challenges
      - Need HI-targets, i.e. Au
      - Analyzing power as function of $\sqrt{s}$
      - More spatial needs for polarimeter
      - Statistical power → obtain polarization lifetime and the bunch polarization profile

H-jet: details of Measurement from RHIC



Same issue as for pC polarimeter

- ❑ Collision related background leaks under the signal "Banana"

→ need to follow similar mitigation strategy

BUT: no alternative absolute polarimeter

All the same problems for a polarized D and He-3 beams

PLUS

what happens if He-3 from beam breaks up during scattering with target?